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Automation of Emergency Measures Planning for Municipalities at Risk of Flooding

Acknowledgments

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Executive Summary

This project is part of an ongoing effort to apply current flood risk study methodologies to the specific problems and needs of municipalities with regard to emergency measures planning for exceptional flooding. Exceptional flooding is becoming more and more common throughout the world, as evidenced by recent events in Canada (specifically the Saguenay and Red River floods), France, and England. Municipalities facing this increasing risk of exceptional flooding must better prepare themselves to deal with such situations by adequately planning their responses and the overall management of these crises.

Various methods currently exist for evaluating risks and impacts due to flooding. Automated tools that implement these methods permit the estimation of property damage and the number of people affected by a flood. One of these tools is DOMINO, developed several years ago by Hydro-Québec and the École Polytechnique, and since used in numerous natural flood risk and potential dam break studies. Experience gained in conducting these studies revealed that some information that is essential when developing emergency plans for the municipalities concerned is not extracted, calculated, or interpreted by any currently available tools.

The work described in this report aimed to correct this deficiency by developing an operational flood impacts evaluation tool based on the civil security needs of municipalities. The overall approach was to couple hydraulic and cartographic simulation technical expertise with civil security expertise.

The first part of the work consisted of developing a computer tool for automatically creating impact curves for evaluating plausible maximum flooding conditions. This tool is based on established hydraulic analysis methods, and facilitates the completion of practical and operational flood impact studies. The second and more theoretical part of the work developed concepts for automatically interpreting these impact curves. To take this work beyond the theory would involve producing a set of impact curves for a municipality and applying the interpretation concepts on a test basis. It would then be possible to make practical adjustments to these concepts for incorporation into a true decision assistance tool for developing municipal emergency plans to counter flood risks.

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1.0 Development of an Operational Tool

1.1 Introduction

The first part of the work undertaken in this study was aimed at obtaining concrete results by developing an operational flood impacts evaluation tool based on the civil security needs of municipalities. This computer tool extracts information pertinent to emergency measures planning needs for exceptional flooding in municipalities from results files produced by flood damage calculation software packages. This information takes the form of curves or nomographs representing sensitive and essential entities affected by floods for municipalities, based on water levels. They must be structured and presented in the form of graphs or impact curves that illustrate all the relevant information and identify sensitive points from the planning, management, and return-to-normal points of view.

There are several tools for evaluating building damage, but we chose a tool developed by our partner Hydro-Québec in collaboration with the École Polytechnique – the DOMINO software package. Our work uses the standard of DOMINO-type results output files, but later, we will be able to use data in this standard from any flood damage evaluation system. This software will then be presented so that the reader can understand the numerical logic underlying the production of impact curves.

To automate impact curve creation, it is necessary to carefully evaluate the real needs of emergency measures authorities. In addition, it is necessary to develop a tool that meets basic and essential needs, then to evaluate how successfully it has been implemented in emergency plan development mechanisms, before creating a large-scale tool requiring much more substantial resources. So, with our partner, the Civil Security Centre of the Urban Community of Montreal, we determined the basic needs for developing flood emergency plans. Obviously, constraints imposed by the nature of the information contained in DOMINO-type results files must be taken into account. Thus, impact curves must be produced using information taken from property assessment codes combined with an evaluation of damages to buildings and their contents naturally calculated by DOMINO. Information is available on people who might be affected by floods. We therefore present the results of this work, which has allowed us to produce seven basic impact curves.

When using DOMINO, one must first define a flood zone. The guiding principle for impact curves is providing information for a set of water levels so that emergency measures authorities can prepare for all possible situations. We must therefore define a plausible maximum flood zone and then calculate damages for all water levels between no flooding and this maximum zone. In addition, geographical, hydraulic, and administrative constraints must be taken into account in order to make the impact results as consistent as possible. All this initial characterization work consists of an impacts study. It will therefore be described in detail to give the reader a clear understanding of the mechanisms used to obtain DOMINO-type results files.

Finally, an overview of the computer tool is presented. Examples of the results produced are given, along with a user's manual.

1.2 Description of the DOMINO Software Package

The DOMINO (DOMmages INOndation) software package is totallly dedicated to estimating flood-related damages. It incorporates an automated method developed by École Polytechnique de Montréal researchers for Hydro-Québec (SOBEK 1998, Gagnon 1998).

This software package can be used to delimit geographical sites that might be subject to flooding in areas bordering waterways and reservoirs and to construct digitall models of these sites' natural terrain using relief data (off-the-shelf digital or digitized cartography). It receives and interprets instantaneous local water levels calculated using digital flow modells such as FLDWAV (Fread D.L. and Lewis J.M. 1998) and SERUM (March 1993) to provide flood limits for each potential rupture scenario. It can also be used to make water surface models and establish intersections with the natural terrain, which represent flood limits.

The property assessment rolls of municipalities located along waterways are incorporated into the digital natural terrain model. Therefore, building locations are known. Knowing the flood limits on the natural terrain makes it possible to identify buildings located inside the flood zone, to assess the value of buildings and their contents, and to estimate how many people live in these buildings. Finally, these analyses can be used to determine, within a flood zone, the number of people who might be affected, the number and value of flooded properties, property affected, and damages caused to local infrastructures and entities.

First, the results are expressed graphically by superimposing the position of buildings and infrastructures on a map of the flood zone as well as numerically in the form of tables, summarizing financial damages and the number of properties and people affected. When these analyses have been completed, the impacts of ruptures in terms of the number of people affected and damages to property and entities in the community are known, along with the details for each scenario.

DOMINO performs the calculations in the following order:

- it creates a digital terrain model;
- it creates a reference water surface;
- it creates water surfaces for each flood scenario;
- it defines the flooded zone between the intersection of the reference water surface and the surface of the land, and the intersection of the flood water surface and the surface of the land;
- it positions buildings and counts those located in the flood zone;
- it totals damages to all buildings and their contents and persons at risk (a building's contents include its interior components and its furnishings); and
- it writes the overall results into a Microsoft® Excel file format.

Appendix A shows as an example, part of a DOMINO results file. The tool developed in the context of this project must use this information. We therefore describe the contents of files of this type below.

Region	Name of the region being studied
Site	Name of the site being studied
River	Name of the river or body of water being studied
Analysis time	Computer processing time
Analysis variant	Name or number of the scenario being studied
Reference time	Reference variant processing time
Reference variant	Name or number of the variant being studied
Regime	Characterization of the flow regime studied
Impact on occupants	Identification of the total number of persons who might be affected
Impact on buildings	Identification of the total value and number of affected buildings
Impact on building contents	Identification of the total value of the contents of affected buildings
Municipality	Municipality's name
Municipality code	Municipality's code
Registration no.	Building's registration number, used to identify assessment units; it is used to precisely locate buildings on topographical maps
Building code	Parameter used to identify specific buildings; usually equals 0
Street address	Entity's address
Use code	Code taken from the property assessment roll. This code is used to determine the nature and type of affected buildings.
No. of floors	Number of floors in a building
Easting/Northing	Information used to precisely locate the land's centroid – depends on the geographic system used
Land elevation	Elevation of the land above or below sea level
No. of occupants	If available, the number of occupants (if equal to 0, the 2.2 persons per building rule is used)
Building value	Building value used for municipal assessment purposes (this is not the market value)
Land value	Land value used for municipal assessment purposes (this is not the market value)
Building chainage	Position of a building relative to a waterway; value calculated by DOMINO
Flooded bank	Position of a building relative to a waterway (right or left bank relative to the direction of flow)
Flow depth	Height of the water level at the centre of each piece of land for the scenario being studied
Flow speed	If known, flow speed at the centre of each piece of land for the scenario being studied
Occupants / buildings / contents weighting factors	Weighting factors for estimating possible losses of life and damages to buildings and their contents. These factors are described below.

No. of occ. who might be affected	The number of people who might be affected by a flood. The rule used is 2.2 persons per housing unit. This value is multiplied by the occupants weighting factor.
Damages to buildings	Damages to buildings equal the value of the building multiplied by the buildings weighting factor
Damages to contents	Damages to contents equal the value of the building multiplied by the contents weighting factor

Also, the DOMINO software package summarizes the table results obtained and presents the following data under the heading "Total Damages":

- number of people who might be affected by the flood
- monetary losses on buildings and number of buildings affected
- monetary losses on building contents

The damage weighting factors used in DOMINO comes mainly from the ASCE (1988). The DOMINO software package considers only damage to buildings and their contents and potential losses of life. Impacts are estimated based solely on flow depths and speeds, if these are known.

Building losses

Building losses are evaluated as a percentage of the amount of their municipal assessment. Flow is assumed to be in free water – that is, that there is no floating ice, debris, or wood present. The weighting factor multiplying the assessment amount is the higher of the two factors F1 and F2 below:

Factor F1, weight based on the product of depth and speed:

depth * speed $< 1.86\ m^2/s$ F1 = 0
depth * speed $\geq 1.86\ m^2/s$ F1 = 1.25
where: depth is equal to the height of the water above the natural terrain
speed is evaluated at the centre of the entity

Factor F2, weight based on depth:

$1.22 <$ depth ≤ 1.83 m	F2 = 0.20	
$1.83 <$ depth ≤ 2.44 m	F2 = 0.25	
$2.44 <$ depth ≤ 3.05 m	F2 = 0.50	
$3.05 <$ depth ≤ 3.66 m	F2 = 0.80	
depth > 3.66 m	F2 = 1.25	(Market value is considered to be 1.25 times the assessment amount)

where: depth is equal to the height of the water above the natural terrain

Contents losses

Contents losses are evaluated as a percentage of the amount of their municipal assessment.

Factor F3 multiplying the assessment amount:

depth < 2 m F3 = 0.1
depth ≥ 2 m F3 = 0.4
where: depth is equal to the height of the water above the natural terrain

Potential losses of life

Potential losses of life are evaluated based on the average number of occupants per house. This number is set at 2.20, which is the average occupation rate in Quebec. This notion comes from dam breaks and not from natural floods. To determine potential losses of life, alert times – an unknown parameter – must be taken into account. However, this value indicates the number of people affected by a flood.

The weighting factor F4 multiplying the number of occupants per house is determined by choosing the higher of the following:

depth < 1 m F4 = 0
depth ≥ 1 m F4 = 1
product of depth * speed < 0.65 m^2/s F4 = 0
product of depth * speed ≥ 0.65 m^2/s F4 = 1
where: depth is equal to the height of the water above the natural terrain
speed is evaluated at the centre of the entity

This information, in whole or in part, is used to produce impact curves. They can be adjusted at any time in DOMINO.

1.3 Impact Curves

The DOMINO software package was originally designed to provide evaluations of damages relating to flow scenarios in the context of natural flooding evaluation and dam break risk studies. The uses of the computer tool that we want to develop goes beyond this. The results must be useable in all phases of emergency measures planning: risk communication, emergency measures planning, emergency situation management, and return-to-normal activities.

A desire to provide results that can be easily used and interpreted by people who are not experts in hydraulics guided our work. Therefore, we want the results to be presented in the form of concrete curves or nomographs and be directly useable. They must be visual, diversified, and suited to the work of emergency measures managers. Thus, already interpreted results are made-to-measure and multi-scenario use tools.

With the assistance of emergency measures authorities who are partners in the project, we identified the minimum information that must and can be extracted from DOMINO-type files.

Use within municipalities of the created tool will allow the validation of these results. The second part of the project deals with automatic impact curve interpretation methodology principles that will then be usable.

In the sections that follow, we present the basic impact curves that we must create automatically with the computer tool, along with a justification of their uses in emergency measures planning activities.

1.3.1 Basic Impact Curves

The needs of emergency measures managers and planners are many and varied. The process undertaken to automate impact curve creation is therefore vast and can only be accomplished through a step-by-step approach. The first step is defining the essential needs of stakeholders in emergency measures that are compatible with the information contained in DOMINO-type files.

The curves or nomographs must be presented in a visual and diversified form that is suited to the needs of emergency measures authorities, in order to provide a more accurate and precise picture of current or future situations by incorporating potential problem linkages. In this manner they can be used to visualize and evaluate the magnitude of crisis situations resulting from anticipated or actual floods.

Information that can be extracted from DOMINO-type files can pertain to:

- damage to buildings and their contents;
- people who might be affected; and
- building use, via the use codes defined in property assessment rolls.

Based on this information, we identified, with our partners, needs for information on the following points:

- occupation of the flooded land
- sensitive entities affected by flooding
- amounts of losses on buildings and building contents
- the population affected

All this information is available from the appropriate property assessment codes (Quebec City, 1999). The impact curves for these points differ in terms of presentation and content. They are explained below in terms of the graph type (bar chart or curve), the number and nature of the information contained in these graphs and the property assessment codes for each piece of information.

An example of these graphs will be provided when the computer tool is presented in Appendix B.

Land occupation:

- Graph type: bar chart
- Graph's abscissa: water level value (m)
- Graph's ordinate: number of entities
- Number of pieces of information: 5

Information and codes list:

- Retail stores (codes 5211 to 5270, 5310 to 5399, 5411 to 5499, 5511 to 5599, 5610 to 5699, 5711 to 5740) and shopping centres (codes 5001, 5002, 5003, 5004, 5005)
- Collective entities and public utilities (codes 4811 to 4890 and 4921 to 4990)
- Office buildings (code 6000)
- Light and heavy industries (codes 2011 to 2999 and 3011 to 3999)
- Parks (codes 7610 and 7620), nature reserves (code 9211 to 9219), golf courses (codes 7392, 7411, 7412), vacant lots (codes 7221 to 7229, 9100, 9220, 9900)

Sensitive crisis management entities:

- Graph type: bar chart
- Graph's abscissa: water level value (m)
- Graph's ordinate: number of entities
- Number of pieces of information: 3

Information and codes list:

- City halls (code 6710)
- Police stations (code 6721)
- Fire stations (code 6722)

Sensitive life support entities:

- Graph type: bar chart
- Graph's abscissa: water level value (m)
- Graph's ordinate: number of entities
- Number of pieces of information: 3

Information and codes list:

- Health services: Hospitals (code 6513), local community services centres (code 6532), other institutions (codes 6542, 6531, 6539)
- Filtration plants (water) (code 4832)
- Treatment plants (sewage) (code 4841)

Miscellaneous sensitive entities:

- Graph type: bar chart
- Graph's abscissa: water level value (m)
- Graph's ordinate: number of entities
- Number of pieces of information: 4

Information and codes list:

- Schools (codes 6811 to 6814, 6821 to 6823)
- Day care centres (codes 6541, 6543)
- Churches (codes 6911, 6919)
- Seniors' homes (codes 6531 and 6539)

Total sensitive entities:

- Graph type: bar chart
- Graph's abscissa: water level value (m)
- Graph's ordinate: number of entities
- Number of pieces of information: 3

Information list:

- Category 1: sum of sensitive crisis management entities
- Category 2: sum of sensitive life support entities
- Category 3: sum of miscellaneous sensitive entities

Amounts of losses on buildings and contents:

- Graph type: curve
- Graph's abscissa: water level value (m)
- Graph's ordinate: amounts ($)

There are 3 curves on this graph:

- Losses on all flooded buildings (all codes included)
- Losses on flooded residential buildings (code 1000)
- Losses on the contents of all flooded buildings (all codes included)

Curve calculation:

- for each water level elevation (Z) : Depth = Z - Land elevation
- look for units with the proper code whose land elevation $\leq$ Z
- for buildings:
  - Loss = Building value * F1 where F1 is a weighting factor
  - 1.22 < depth $\leq$ 1.83 m F1 = 0.20
  - 1.83 < depth $\leq$ 2.44 m F1 = 0.25
  - 2.44 < depth $\leq$ 3.05 m F1 = 0.50
  - 3.05 < depth $\leq$ 3.66 m F1 = 0.80

    - depth > 3.66 m F1 = 1.25
    - These losses are cumulated
- For contents:
    - Loss = building value * F2 where F2 is a weighting factor
    - Depth < 2 m F2 = 0.1
    - Depth ≥ 2 m F2 = 0.4
    - These losses are cumulated

Population affected:

- Graph type: curve
- Graph's abscissa: water level value (m)
- Graph's ordinate: number of people
- There is one curve on this graph:
    - People in all the flooded buildings (all codes included)

Curve calculation:

- for each entity whose land elevation ≤ the water level elevation
- take the value for the number of occupants affected
- cumulative value of the number of occupants affected

These graphs have several uses in the field of emergency measures. These are described below.

1.3.2 Possible Uses of Basic Impact Curves

Basic impact curves can be used in risk communication, in emergency plans and measures prevention, preparation and planning, in mitigation measures development, and in return-to-normal activities. These results show the importance and usefulness of impact studies for municipalities.

1.3.2.1 Risk Communication

All emergency measures authorities should be involved in the risk communication process so they can put joint emergency plans, mitigation measures, alert mechanisms, and so on in place. The diversity of the results of impact curves makes it possible to target those involved and to adapt and orient the contents of communications. More specifically, diagrams showing sensitive entities can be used to evaluate the various municipal services that should be part of the emergency measures planning process. At this stage, the curves on buildings, affected population and land occupancy are mostly used to raise the awareness of municipal authorities concerning flood risks.

1.3.2.2 Emergency Measures Prevention, Preparation and Planning

The results of impact curves allow authorities to better understand and assimilate situations resulting from floods and to prepare for them.

Emergency plans can take potential problems that might arise into account, incorporate the flooding of essential sensitive entities (City Hall, police stations, and fire stations), and develop intermunicipal and interorganizational agreements to deal with them. Health-related facilities are important in terms of evacuation on the one hand, since they require special logistics, and in planning the replacement of the services they provide the affected population on the other hand.

Water filtration and sewage treatment plants are entities that must be incorporated into all municipal emergency plans since they are life support systems which are essential to the municipality, as well as to other municipalities that might not be directly affected by a flood.

The curve showing the population affected can be used to plan the magnitude of potential evacuations and to predict the resources needed to carry them out. Various sensitive facilities also allow authorities to provide accommodation sites outside the flooded zone. Schools and day care centres pose a special problem with respect to evacuation and planning for family reunification.

The land occupation graph can be used to adapt municipal planning and development plans to deal with flood risks. Mitigation measures can also be foreseen and planned, as can be the domino effects arising from the flooding of certain industries. Finally, this graph can be used to assess potential social disorganization resulting from the flooding of stores and shopping centres.

These results are particularly useful in planning and conducting flood response exercises, which should be an integral part of any emergency plan. Using impact curves, it is possible to define precise study scenarios and to determine whether all those concerned are adequately evaluating the situations presented, and to change situations based on the participants' level of response.

1.3.2.3 Emergency Situation Mitigation and Management

In emergency situations resulting from floods, these results allow authorities to visualize the magnitude of a crisis and to predict its progress. They also make cascading emergency situations (domino effect) more predictable. Thus, response to flood victims is better prepared and suited to the situation, while resource management is optimized. In short, these graphs allow emergency measures authorities to be more proactive when faced with exceptional flooding.

In emergency situations, these nomographs provide better communications regarding the current situation and its progress. This communication can be directed to the public, the media, or other organizations.

1.3.2.4 Return to Normal

By making it possible to evaluate the progress of emergency situations during exceptional floods, impact curves provide authorities with the knowledge they need to plan returns-to-normal in terms of human and financial resources. The presence of water requires specific actions to be

taken to ensure that conditions are healthy and clean before people return. These curves can be used to plan these activities very early on in the crisis and to optimize the resources to be used.

1.4 Impacts Studies

Impacts studies, seen from the civil security point of view, involve first determining impacts on the population, on property, and on all structures affected in potential flood zones, and then evaluating the nature and magnitude of the resulting emergency situation. The results of such studies consist of impact curves derived from hydraulic studies of major and exceptional but plausible floods. Using these results allows municipalities that might be affected by such floods to better prepare themselves and to adapt their emergency plans to these situations.
The study methodology we developed is presented to support the definition of the basic impact curves to be incorporated into municipal emergency plans. This methodology is applied to exceptional floods, but it can be adapted to any other emergency situation.

To carry out such a study, a hydraulic analysis of exceptional flows must first be conducted to determine the plausible maximum water levels that might be reached. Then, the territory must be segmented based on standard criteria. Finally, the impact study proper is done. These steps are presented in detail below.

1.4.1 Hydraulic Analysis

The main thrust of a flood impact study is to provide useable results whatever the magnitude of the predicted flood. It is based on determining maximum but plausible water levels in order to delimit a realistic territory to cover. The study may be used to evaluate not only the impacts of maximum flooding but also impacts at lower water levels. Thus, all situations that might arise will be covered by these results. Moreover, from the emergency preparedness point of view, it is possible to prepare for the worst while establishing gradations based on critical water levels in terms of impacts. These gradations then reflect increases in the severity of the impacts that might arise. For example, they might correspond to the values at which a hospital, a police station, or a fire station is flooded.

To do this, flow levels are calculated, taking into account the most severe assumptions possible for the waterway (i.e., the Maximum Probable Flood Level [MPFL]). The resulting potential rupture waves represent the maximum flood conditions that could occur. Normally, no major exceptional flood should reach or surpass these water levels. Therefore, the results produced will be directly useable in all circumstances. Impacts can also be evaluated for all lesser depths.

Based on this hydraulic information, territory segmentation may begin, followed by the impact study itself.

1.4.2 Territory Segmentation

Study results are most useable by municipal emergency measures authorities. Diversity among these must be taken into account, as well as the fact that several municipalities might be affected within the territory covered by a hydraulic study. Likewise, hydraulic flow behaviour must be considered to give realistic and adequate flood values for riverbank heights. It is important for

authorities to know the proper depth of the water for the infrastructures being studied. It is therefore imperative to correctly segment the territory geographically. The segmentation criteria used are as follows:

- hydraulic uniformity
- geographic uniformity
- municipal boundaries

Each of these criteria is explained in the following section.

1.4.2.1 Hydraulic Uniformity Criteria

Segmentation based on hydraulic uniformity is important since that allows us to have uniform hydraulic behaviour for specific zones. If we know the water level at one point in a zone, we know or can evaluate water levels throughout the zone. This evaluation might be the result of direct interpretation or follow from a series of hydraulic flow characterization calculations.

Zones that can be directly interpreted hydraulically are supposedly horizontal bodies of water, such as lakes. In this case, there can be some level differences between inflow entry points and outlets when there are severe flood waves. The error is negligible if the body of water is large and the volume of water it can hold is great.

The other cases are zones bordered by a river where interpretation, following a series of hydraulic calculations, is necessary. In the same area, a uniform torrential or river flow must be maintained. To do this, calculating the free surface gives adequate information. Moreover, natural and artificial hydraulic obstruction points must be evaluated. The most commonly found hydraulic obstructions are:

- natural:
  - sills, such are rocky bars
  - major narrowing of flow sections
  - steep flow slopes, with areas of rapids
- artificial:
  - dams
  - sills
  - bridges
  - dikes

When delimiting hydraulically uniform zones, care must be taken to ensure that the hydraulic obstruction points are permanent and valid for all flow levels. They must not be submerged when there is the least increase in water levels, or simply create local hydraulic rises that do not significantly affect flow.

1.4.2.2 Geographic Uniformity Criteria

Segmenting territory into geographically uniform zones makes it possible to not only make hydraulic impacts uniform in terms of water levels and flow speeds, but also the geology of areas where there is a risk of landslides after flooding. Delimiting zones that are geographically

uniform can only be accomplished by analyzing topographical and geological maps. If such maps are not available, a direct analysis must be done in the field or by consulting municipal officials with a thorough knowledge of the land.

Thus, the criteria used are:

- land slope uniformity: zones must have uniform natural land slopes. Slope variations of more that 20% cause substantial variations in flow conditions. Zones bordered by large cliffs or embankments must be studied separately;
- geological uniformity: zones must be geologically uniform as regards landslide and soil liquidification risks. Clayey or very sandy zones must be studied separately.

1.4.2.3 Municipality Boundaries Criterion

To adequately plan responses to emergency situations, impact studies must take into account municipal legal boundaries and any cooperation agreements that may exist between municipalities. The results presented then must take these regional disparities into consideration.

1.5 CONSEQ: An Automatic Impact Curve Creation Tool

A computer tool was consequently developed to automatically create basic impact curves from DOMINO-type files. It is called CONSEQ because of its use.

This program was developed in Microsoft® Excel in order to use the same format as the results files that it has to process. Users define the files they want to process, choose the number of points or the calculation intervals for the curves and the impact curves are generated automatically. These results can then be saved or printed. Appendix B provides an example of impact curves calculated in this way.

This program was tested at a large number of sites studied by our team during prior risk study projects (Appendix B). It was carefully evaluated at sites located in the Montreal area and at sites near the Beauharnois hydroelectric facilities on the Saint Lawrence River. The results cannot be presented in this report since they have not been formally provided to the municipalities concerned.

Our validation work showed that very significant time savings (of almost 60%) are achieved when these curves are created automatically rather than manually.

Contacts with municipalities to which preliminary results were presented indicate that the impact curves will be well-received and will be used. Subsequent studies must be done to evaluate the actual penetration rate and use of these curves.

Readers can obtain the CONSEQ tool and a DOMINO-type results file by contacting OCIPEP.

2.0 Theoretical Work: Methodological Bases for Automatic Interpretation of Impact Curves

2.1 Introduction

The preceding work allowed us to develop a computer tool (CONSEQ) which creates impact curves containing essential and basic information for developing emergency flood plans in municipalities. These impact curves are produced using a DOMINO-type results file, which contains information taken from the property assessment roll of a municipality (Quebec City, 1999) that might suffer flooding. Generated automatically, they describe the damage caused by these floods in an easy-to-interpret graphic form.

Research work carried on jointly with our partner, the Civil Security Centre of the Montreal Urban Community, made it possible for us to identify supplementary development avenues to make this computer tool still more powerful for assisting in the development of emergency flood plans. This work was undertaken with the aim of defining the methodological principles needed to develop a real decision assistance tool designed to guide civil security authorities in their work. Such a tool would have three specific steps. In the first step, the exposure levels of municipalities at risk of flood are evaluated. In the second step, impact curves appropriate to the municipalities' level of awareness and preparedness for this risk are produced. Finally, in the third step, methodologies are developed for creating failure curves. This is the last step in evaluating and interpreting impacts before they are incorporated into effective emergency plans. These three steps are described below.

It should be noted that this work is theoretical in nature. That is, it does not effectively change the CONSEQ tool. However, it does have a pragmatic aspect aimed at developing a real emergency measures decision assistance tool in the future. So, the modified impact curves presented in Appendix C are examples and were not created automatically.

2.2 Evaluation of Levels of Exposure to Flooding

Flooding of a municipality is an emergency situation since there are always affected people who must be evacuated. This aspect is automatically covered with this tool. However, for civil security authorities, it is important and essential to have an overall picture of the situation. This picture obviously includes not only the number of people affected but also essential entities for crisis management, life support systems, transportation infrastructures, and serious potential environmental impacts that might result from the flooding. The municipality's exposure level is evaluated based on an analysis of this picture.

Information taken from DOMINO-type files can be used to produce quite a complete picture of the situation. Appendix D shows all the entities in municipalities that can be identified using the codes found in a property assessment roll (Quebec City, 1999). However, only essential information is used at this stage.

The notion of exposure level must first be defined in order to have a constant and uniform scale. A simple and effective syntax was developed with emergency measures authorities. It can be

refined over time and with use, but it has the benefit of establishing the foundations for such an approach. The four levels are defined as: (1) minor, (2) serious, (3) severe, and (4) very severe.

Their meanings are:

- minor exposure level: few or no entities are affected by the flood – for example, only a small part of the population or no sensitive entities are flooded;
- serious exposure level: several entities are affected by the flood – for example, a significant proportion of the population or some sensitive entities are flooded;
- severe exposure level: many entities are affected by the flood – for example, a very large proportion of the population or many sensitive entities are flooded;
- very severe exposure level: a very large number of entities are affected – for example, most of the population or most sensitive entities are flooded.

This exposure level is evaluated for each of the entities in the picture of the situation as described below, along with its possible representation in a computer tool (Appendix C).

2.2.1 Population

The greater the number of people affected in a municipality by a rise in water levels, the harder the situation is to manage in terms of civil security. The following rules may be used. They were developed in consensus with various emergency measures authorities and may be modified with use.

- If less than 5% of a municipality's total population is affected, the exposure level is minor.
- If from 5% to 20% of a municipality's total population is affected, the exposure level is serious.
- If from 20% to 50% of a municipality's total population is affected, the exposure level is severe.
- If more than 50% of a municipality's total population is affected, the exposure level is very severe.

In a computer tool, exposure level limits are calculated based on the total population and placed on an impact curve graph for the population. It is obvious that not all limits are necessarily reached in all municipalities.

In managing an expected crisis, when a predicted water level is given, the situation is immediately known. In terms of emergency measures planning, the values defining exposure levels are clearly identified. Evacuation and accommodation arrangements can then be planned more effectively in terms of material and human resources.

A graphical representation of this concept is given in Figure 1 of Appendix C. Table 2.1 summarizes the results obtained for a municipality. This table supplements the appended figure.

Table 2.1 Example showing exposure levels of the population in a municipality at risk of flooding

Water level value	Exposure level	Percentage of the population affected
20 m - 21 m	minor	5% or less
21 m – 23.50 m	serious	5% - 20%
23.50 m – 26.70 m	severe	20% - 50%
26.70 m - 28 m	very severe	over 50%

2.2.2 Crisis Management

For municipalities, during crises, the loss of certain crisis management entities creates a more complex situation. Appendix D shows these entities, which can be identified using property assessment codes. They can therefore be evaluated in DOMINO-type files. A municipality's exposure level is a direct function of the number of these entities potentially affected by a flood. The rules for evaluating this level are given below. They were determined in consensus with various emergency measures authorities and may be modified with use.

- If no entity is affected, the exposure level is minor.
- If only one entity is affected, the exposure level is serious.
- If at least three entities are affected, the exposure level is severe.
- If more than three entities are affected, the exposure level is very severe.

Summary tables show this exposure level based on water level values. The following table shows an example of this. It summarizes the graphical representation of this concept contained in Figure 2 of Appendix C.

Table 2.2 Example showing exposure levels for crisis management entities in a municipality at risk of flooding

Water level value (m)	Exposure level	Crisis management entity(ies) flooded (cumulative)
20	minor	
21	minor	
22	serious	Police station
23	serious	
24	serious	
25	severe	Fire station (station X) City Hall
26	very severe	Fire station (station Y)
27	very severe	
28	very severe	

In managing an expected crisis, when a predicted water level is given, the situation is immediately known. In terms of emergency measures planning, the values defining exposure levels are clearly identified. Preventive relocation measures can then be planned more effectively and it is possible to provide the material and human resources needed to carry them out.

2.2.3 Life Support Systems

The exposure level logic, method of representation and use for life support systems is the same as those developed for the crisis management entities described above (Figure 2 in Appendix C and Table 2.2), since this information is compiled in a similar bar graph. Likewise, Appendix D shows life support system-related entities that can be identified using property assessment codes. However, rules for evaluating this exposure level vary. They consider the relative importance of these systems, as determined with municipal officials. Loss of a filtration plant (water) is more damaging, in terms of civil security, than the loss of an electrical infrastructure. Because of these complexities these rules have several components. They were developed by consensus with the assistance of emergency measures authorities and École Polytechnique technical experts.

- If no entity is affected, the exposure level is minor.
- If more than one entity relating to electricity, gas or oil is affected, the exposure level is serious.
- If a filtration plant (water) is affected, the exposure level is very severe.
- If a treatment plant (sewage) is affected, the exposure level is very severe.
- If, for a same value, two exposure levels can be established, the most severe level is retained.

For electricity, gas, and oil systems, property assessment codes cannot be used to refine exposure level evaluation rules since there is no information on the exact nature of the affected infrastructure. It is therefore essential to carefully validate this information at the sites being studied. Information taken from property assessment rolls must therefore be considered as exposure indicators.

2.2.4 Transportation Infrastructures

The exposure level logic, method of representation, and use for transportation infrastructures is the same as those developed for the crisis management entities described above (Figure 2 in Appendix C and Table 2.2), since this information is compiled in a similar bar graph. Likewise, Appendix D shows transportation infrastructure-related entities that can be identified using property assessment codes. However, evaluation rules for this exposure level vary. It should be noted that property assessment codes could not be used to refine exposure level evaluation rules since there is no information on the exact nature of the affected infrastructure. These rules must be refined based on the specific nature of the transportation system in each municipality, which must be defined manually in such a computer tool. However, a consensus was reached, with the help of Montreal subway system emergency measures specialists, on the following general rules:

- If no entity is affected, the exposure level is minor.
- If more than one entity relating to public roads or motor vehicle or marine transportation is affected, the exposure level is severe.

- If an infrastructure relating to railroads, subway systems, or air travel is affected, the exposure level is very severe.
- If, for a same value, two exposure levels can be established, the most severe level is retained.

These rules are based on the principle that the social disorganization resulting from the flooding of railroads, subway systems, or airports creates very serious crisis situations, even if there is no risk of loss of life. It is therefore essential to carefully validate this information at the sites being studied. Information taken from property assessment rolls must therefore be considered as exposure indicators.

2.2.5 Environmental Impacts

The exposure level logic, method of representation and use for environmental impacts is the same as those developed for the crisis management entities described above (Figure 2 in Appendix C and Table 2.2), since this information is compiled in a similar bar graph. Likewise, Appendix D shows industry-related entities with potential environmental impacts that can be identified using property assessment codes. However, these property assessment codes neither give the exact nature of the environmental risks nor indicate whether they in fact exist since there is no information on the exact nature of the industries or the products they use. The following rules, developed in consensus with our partners, must be refined based on the specific conditions of these industries in each municipality:

- If no entity is affected, the exposure level is minor.
- If only one entity is affected, the exposure level is serious.
- If at least three entities are affected, the exposure level is severe.
- If more than three entities are affected, the exposure level is very severe.

It is therefore essential to carefully validate this information at the sites being studied. Information taken from property assessment rolls must therefore be considered as exposure indicators.

2.2.6 Overall Evaluation

A municipality's exposure level to flood risks is an indicator that can be used to rapidly obtain a picture of the seriousness of the situation resulting from it. Five intermediate levels are defined: (1) the population affected, (2) crisis management entities, (3) life support systems, (4) transportation infrastructures, and (5) environmental impacts. An overall exposure level summarizing the above can then be produced based on the following principle:

- The overall exposure level is equal to the highest level found for a given water level value.

For example, if the exposure level is minor for people and severe for crisis management entities, the overall exposure level is severe.

A table identical to Table 2.2 is then created, indicating where the exposure level came from.

2.2.7 Exposure Level Determination and Use

To establish these exposure levels as described above, the entire DOMINO-type file in the plausible maximum flood zone must be scanned, as for the CONSEQ tool that was developed in the first part of this study. For all intermediate water levels between the start of the flood and its maximum level, exposure levels are calculated for the affected population, crisis management entities, life support systems, transportation infrastructures, and environmental impacts. Then the overall exposure level is calculated. These results are presented to the user in the form of graphs and tables so that he/she can rapidly assess the situations that he/she must eventually face. Critical water level values are then clearly shown. The limits set for each category and for each exposure level (minor, serious, severe, and very severe) equate to critical levels that must be considered in emergency plans.

This information can be used to properly plan future activities in order to develop appropriate flood emergency plans. These activities have to do with validating information and with the resources to be used to evaluate and define the corrective, mitigative, and protective measures to be put in place. They must be carried out in collaboration with a number of different stakeholders from various administrative, technical, and security fields. The following steps, presented in sections 2.3 and 2.4, can be used to refine the evaluation of these resources.

Extended impact curves can also be produced based on exposure levels of sensitive entities that are essential to the municipality. Section 2.3 below shows how these curves are obtained.

2.3 Extended Impact Curve Generation

The content and degree of sophistication of emergency plans depend on the municipality's level of preparedness and awareness. The information that must be provided to municipalities must therefore take this level of preparedness into consideration. The flood of information must be controlled. The only possible approach then is to assist users.

The computer system studies the zone defined by the plausible maximum flood limit, evaluates the available information, and presents an overall picture of the situation to users. The users decide what they want to obtain to carry out their emergency plans based on their preparedness status and on the resources available for this purpose.

Impact curves can be created and provided to users based on property assessment codes for the entities found in the flood zone. In DOMINO-type files, this information is available along with the height of the natural terrain where they are located. The curves can then be produced as explained in section 2.2 of this report. All the entities that might be used to construct these curves are described in Appendix D. In that appendix, these entities are grouped into uniform categories that might be of specific interest in flood emergency plans. These categories are defined by the entities they contain:

- Entities related to various types of housing
- Crisis management entities
- Entities related to health institutions

- Entities related to educational institutions
- Entities related to the military
- Communications entities
- Transportation entities
- Entities related to life support systems
- Entities related to industries with potential environmental impacts
- Entities related to industry and business
- Miscellaneous entities

A decision assistance system of this kind must therefore identify all the entities in Appendix D present in the potential flood zone, then the categories defined above. The categories identified are presented to users, who choose the ones they want to include in their emergency plans. Then, for each chosen category, the system presents users with a list of the entities present. They select the entities for which they want to obtain impact curves at the various water levels included between the bank and the plausible maximum flood level.

Providing too many curves is not beneficial if resources to validate them and adapt them specifically to a municipality are not available. There is, then, a real risk of an overabundance of information to be studied, thereby discouraging users, which might cause the opposite effect – that is, inadequate use of these curves or pure and simple rejection of them.

Likewise, certain categories are more relevant than others. Therefore, a prudent and structured approach must be adopted. Crisis management and health institution entities are critical to the security of the public and require special attention during evacuations because of the difficulty of relocating such functions. Educational institutions must be considered carefully during evacuations not only because families might be separated but also because these buildings often serve as accommodation centres for evacuees. Entities related to the army might also be used for accommodation. Communications, transportation, and life support system entities must be considered very carefully because of the impacts their flooding might have on the public, both within the flooded zone and outside it. Finally, industries posing environmental risks must be made aware of the domino effects that might occur if they are flooded. In this case, it is up to municipalities to ensure that they are well aware of the flood risk and that they have effective and suitable emergency plans in place.

By default, the software can generate results only for crisis management entities, entities related to health, and educational institutions that represent the most severe and sensitive impacts for the municipality. Other entities might be the responsibility of other public or private organizations.

2.4 Emergency Plan Development Assistance

Impact curves like those developed using DOMINO-type files represent basic information that can be used to identify populations, homes, and various entities affected by various rises in water levels. However, this information must be analyzed in greater detail in order to be adequately and effectively incorporated into emergency plans. At this stage, it is possible to define, using specific information collected in the field, failure curves for certain specific entities. To do this, a decision assistance system must first guide users in their search for technical information, using flood data sheets, and later in producing failure curves. These two stages are described in the following section.

2.4.1 Flood Data Sheets

A flood is, by definition, a known natural event that we are able to anticipate but the extent of whose impacts on a territory is unknown. Thus, before proceeding to functionally and technically develop any emergency plan, it might seem necessary to first reflect on the various ways of estimating and limiting the effects of this phenomenon. In other words, it might be advisable, before developing any emergency plan, to ask the right questions so as to be able to deal with any damages the flood might cause.

In developing emergency plans, certain information supplementing that found in assessment rolls and impact curves is needed. Some information on sensitive entities is not given in the assessment rolls provided to DOMINO and cannot be deduced from flood simulations. This would include, for example, the critical water levels at which the electrical equipment at a police station would stop functioning. The person responsible for the municipality's emergency measures must collect such information in the field for each entity. To do this, he/she should not hesitate to ask for advice from more knowledgeable people since the amount, diversity, and technical nature of this information is considerable. The quality of the information collected has a direct effect on the quality and effectiveness of the final emergency plan. A decision assistance system can provide effective help to the people responsible for emergency measures and guide them in the difficult task of collecting and processing information. Flood data sheets are designed with this in mind.

Flood data sheets represent a guide on technical points to be analyzed if certain essential entities are flooded. At present, only the main points have been identified and included in the flood data sheets for seven sensitive entities that are considered to be representative. These entities, whose flood data sheets are shown in Appendix E, are:

- City halls
- Fire stations
- Police stations
- Schools and day care centres
- Hospitals and other health institutions
- Businesses posing environmental risks
- Filtration plants (water)

The points dealt with in these data sheets can be refined over time and based on municipalities' specific needs regarding their use and the resources available. Overall, the data sheets presented in Appendix E deal with the following points:

1. Validation: it is important to check whether information on a entity's geographic position contained in the property assessment roll is correct and up-to-date. The exact location of the entity must be validated and it must be checked whether the natural terrain value is indeed affected by rises in water levels.

2. Functionality levels: administrative and crisis management entities (such as city halls) or technical entities (such as police or fire stations) must perform certain well-defined tasks. During floods, rising water levels might prevent people working there from performing these tasks. However, despite the presence of water, some tasks can still be performed in emergencies. For example, for a fire station, fire trucks can move if there is a small amount of water on the ground. However, beyond a certain level, trucks can no longer operate. Likewise, at a certain water level, the presence of toxic materials might necessitate an immediate evacuation. Therefore there are levels of functionality that vary for each specific entity. The flood data sheets include these levels of functionality and emergency measures authorities must identify them with the help of the technical and administrative people responsible for these entities. For each of these functionality levels, it must be determined at what water levels they become inoperative.

3. Evacuation mechanisms: the important points specific to each entity as regards evacuations are identified. They must lead emergency measures authorities to evaluate and resolve them in collaboration with the administrative and technical people responsible for these entities.

4. Alert mechanisms: this important point is identified so that they are adequately and effectively developed in collaboration with the administrative and technical people responsible for these entities. These mechanisms should also include sets of relevant and suitable exercises.

5. Return-to-normal management: the problem of return-to-normal activities must be identified and resolved in collaboration with the administrative and technical people responsible for the entity. Clean-up activities and mechanisms for gradually restarting activities must be clearly established.

6. Other specific points: for some entities, particular points must be considered, always in collaboration with the administrative and technical people responsible for these entities. Thus, for water filtration plants, measures for remedying a lack of water and for managing fire risks resulting from this lack of water must be put in place. For private businesses, the municipality's emergency measures authorities must ensure that they are notified of the flood risk and that in-house emergency plans are well defined and effective.

Such a decision assistance system would work on the following principle: as soon as an entity is identified in the plausible maximum flood zone and if a user has asked for an impact curve regarding it, a flood data sheet is automatically produced. The person in charge of emergency measures attaches the results of his/her work to the impact curve so that it can all be incorporated into the flood emergency plan.

2.4.2 Failure Curves

Certain decision aids are already available for developing emergency plans. Among other things, impact curves show the water levels reached on various sensitive entities. Information provided on the flood data sheets supplements these curves. It is then possible to add a new concept developed for hydroelectric transportation technical entities: failure curves. Incorporating this concept into municipal emergency plans is innovative and should be put into practice in order to evaluate its real effectiveness and the improvements it provides in planning and managing flood emergencies. That is why in this project we present the general principles governing the production of these failure curves.

Failure curves are based on the functionality levels used in flood data sheets. The functionality values are put on a graph with the water level values. Likewise, failure causes can be represented graphically, based on water level values. There are two types of failure graphs or curves. The graphs concerning the functions of entities affected by floods are failure functional curves. Curves concerning failure causes are called failure causality curves. They are described separately and their potential use will be discussed last.

As with flood data sheets, the data needed to produce these curves cannot be extracted from DOMINO-type files. Decision assistance system users must therefore provide the necessary information. Since these curves are closely associated with flood data sheets, as soon as a data sheet is produced for an entity, the module concerning the failure curves for this entity is activated. The data needed to produce them is listed and forwarded to the user. When the user has compiled it, he/she can reactivate the module and send the data. The curves are then produced and provided to the user.

2.4.2.1 Failure Functional Curves

Flood data sheets can be used to establish specific functionality levels for each entity. For each of these functionalities, based on water level values, impacts must be evaluated in terms of failure or destruction. A scale is needed to modulate these impacts. Thus, four levels are defined and described as follows:

1. Normal level: entity not affected – the flood has no impact.
2. Failure level: entity slightly affected – staff members are not in danger, but activities are disrupted.
3. Non-functional level: entity put out of action by the flood; possible danger for staff members.
4. Destruction level: entity partially or completely destroyed by the flood.

For example, for city halls, three functions associated with crisis management can be identified: (1) telecommunications, (2) municipal services, and (3) emergency services. For each of these,

the four preceding levels must be established in order to draw a specific failure functional curve. Figure 1 of Appendix F shows an example of such a curve for the telecommunications function. Such curves allow users to quickly visualize the impact of reaching a certain water level on the functionality of the entity being studied and to clearly establish critical levels. Some levels, such as functionalities that do not have failure and destruction values, but only non-functional levels, may not be defined.

In certain cases, these levels may never be reached. However, that allows us to know about possible losses of functionality and this knowledge might be useful in studying the impacts of various flood risks.

2.4.2.2 Failure Causality Curves

As with failure functional curves, entities such as city halls have several functionalities whose status must be monitored during floods. All functionalities may be shown in a single diagram. For each of them, the four levels defined for failure functional curves are indicated.

Figure 2 of Appendix F gives an example of a failure causality curve for a city hall.

These graphs summarize all information concerning the functionalities of specific entities. Again, critical levels are easily identifiable and the use of this knowledge goes far beyond the strict context of flood risks.

2.4.2.3 Potential Use of Failure Curves

Essentially, these failure curves allow users to summarize and group information on the non-functionality of certain entities in crisis situations. They should be produced for essential entities such as crisis management entities, and health and education-related entities.

During crisis situations, these curves can be used to rapidly evaluate developments and consult emergency plans based on the predicted status of these entities. Flooding is a situation that evolves and hydraulic experts are usually able to predict future flood levels.

When planning emergency measures, these curves clearly show critical levels so that prevention and mitigation measures can be adapted. This is a major benefit in preparing effective and operational emergency plans.

Evaluation work on failure levels is outside the scope of flood risk, since it creates awareness of the notion of failure among all administrative, technical, and security people. Identifying functionalities that might fail is very useful for assessing vulnerabilities in municipalities and planning possible mitigation measures.

3.0 Conclusion

This work has allowed us to achieve our original goal, which was to incorporate numerical, hydraulic, cartographic, and civil security expertise, all dedicated to developing operational municipal emergency plans to counter flood risks, into a single structured process.

Given the new Quebec legislation on dams and civil security, it is important to create effective and concrete links among waterway managers and municipalities located on waterways. The CONSEQ tool is a first step in this direction. The time savings it can provide in developing emergency plans is a very valuable benefit, particularly if it is combined with the operational direction provided by the impact curves.

The concept of impacts studies is particularly innovative since it makes it possible for all stakeholders to concentrate on the potential but plausible impacts of floods. Its approach – which is not based on specific scenarios – allows all potential situations to be covered and the most adequate preparations possible to be made. It is important to implant this concept in the minds of not only waterway managers but also of municipal emergency measures authorities before developing a real decision assistance tool for developing emergency flood plans. The involvement of our partners in this research and development project ensures that this awareness work will be carried out in the near future.

The flood data sheets developed in the second part of this project are also a good example of the integration of technical concepts associated with flood hydraulics, administrative and management considerations, and emergency measures planning. They should be applied with all stakeholders in order to refine their content.

Failure causality and functional curves are more theoretical concepts whose real worth can only be judged with time. However, they incorporate a set of concepts that concretely concern the use of sensitive entities in flood-related emergency situations that require much preparation and awareness on the part of emergency measures authorities. Their use, then, will depend on municipalities' states of readiness.

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Appendix A – Example of a Domino Results File

Analysis report on flood impacts **Calculated on:** 2001/03/13 - 13:46 **File:** fichier test

Region: A region
Site: A site
River: A lake

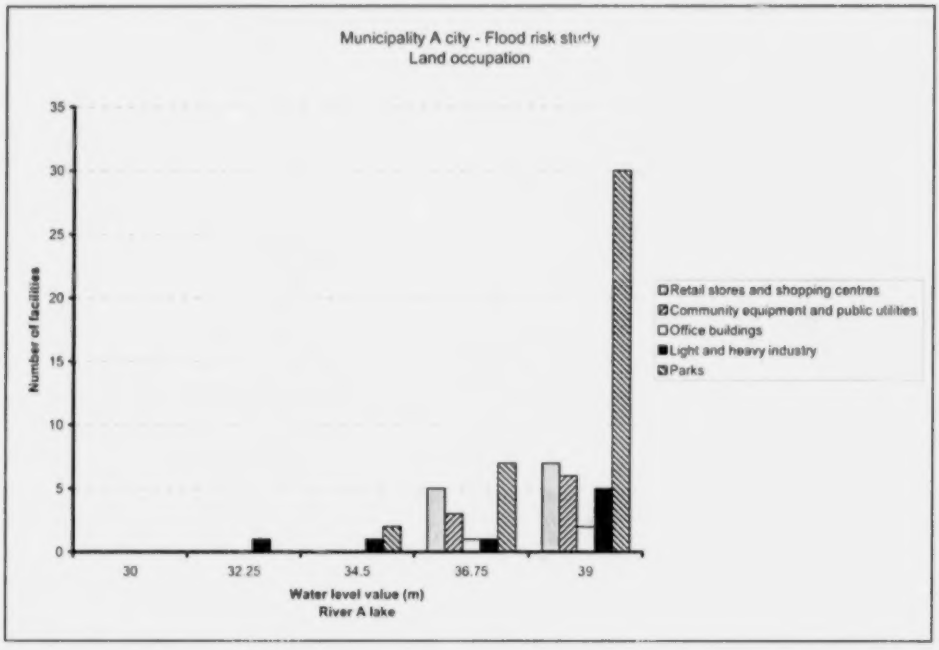
Analysis time: 10.00 **System:** Non-permanent - 1D
Analysis variant: 1
Reference time: 1.00 **System:** Non-permanent - 1D
Reference variant: 0

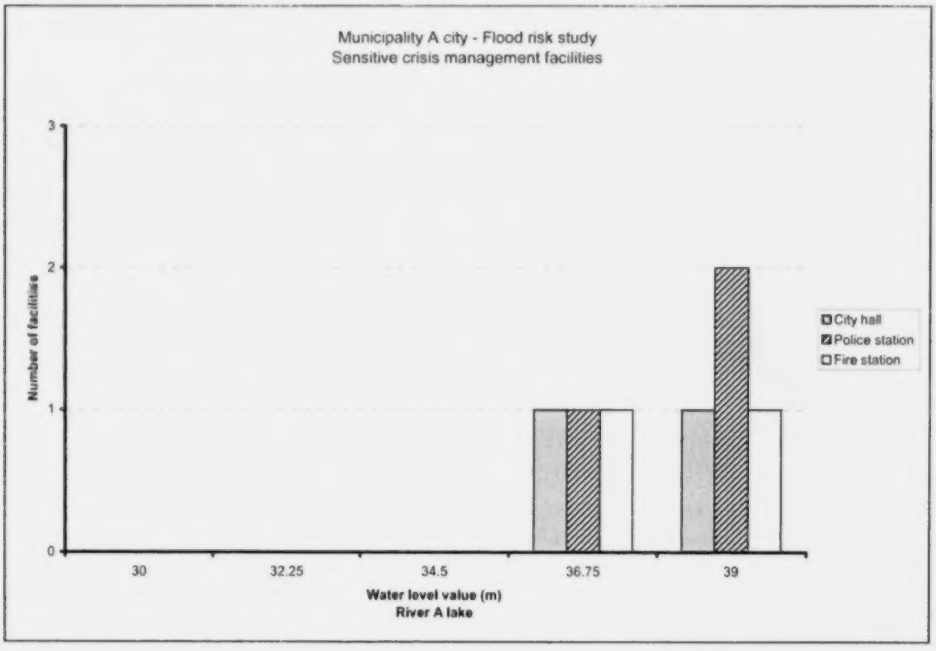
Identification weighting criteria sets:
Impact on occupants: Population
Impact on buildings: Buildings
Impact on building contents: Contents

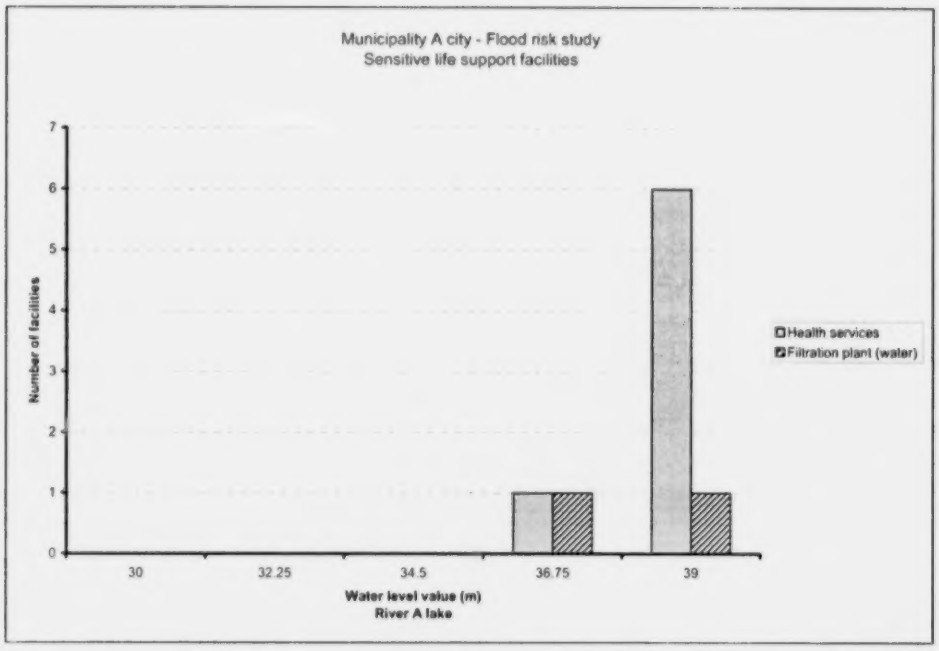
Total damages:
288 persons
$ 19226405 on 385 buildings
$ 12470300

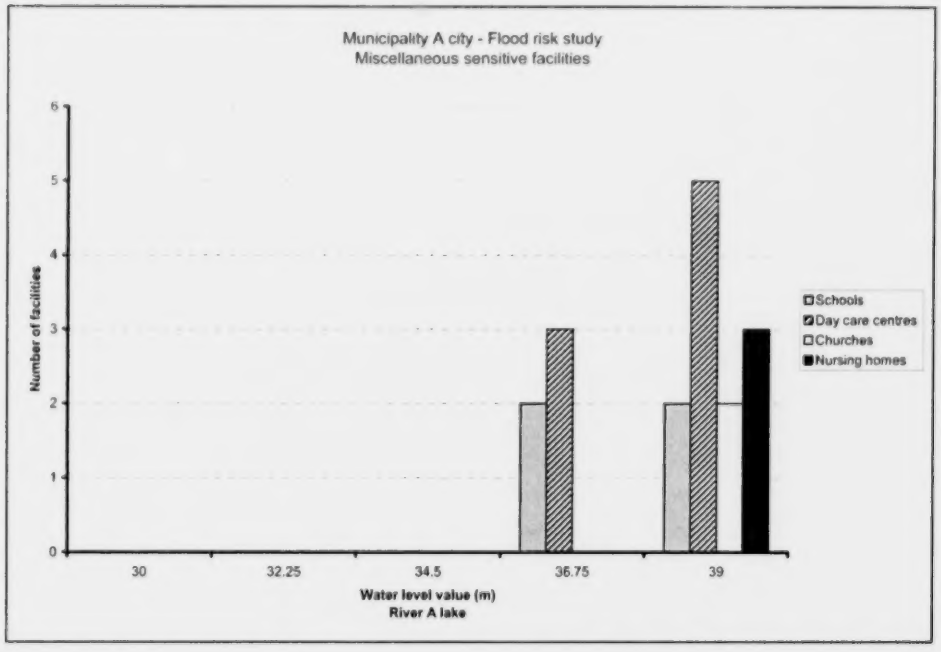
Munici -pality	Munic. code	Reg. no.	Build -ing code	Street address	Use Code	No. of floors	Easting	Northing	Land elevation	No. of occu-pants	Building value	Land value	Building chainage	Bank flooded	Flow depth	Flow speed	Weight fact. occupants	Weight fact. buildings	Weight fact. contents	No. of occ. potent-ially affected	Damage buildings	Damage contents
A city	99999	9999 -99- 9999	0	99 A street	1000	1	274557	5016725	36.51 (c)	0	53400	57900	2175.17	Right	1.487	0.000	1	0.200	0.100	2.20 (dm)	10680	5340
A city	99999	9999 -99- 9999	0	99 A street	1000	1	274627	5016570	37.22 (c)	0	87500	10800	2337.55	Right	0.780	0.000	0	0.000	0.100	0	0	8750
A city	99999	9999 -99- 9999	0	99 A street	1000	1	274642	5016630	37.82 (c)	0	70100	15100	2268.60	Right	0.178	0.000	0	0.000	0.100	0	0	7010
A city	99999	9999 -99- 9999	0	99 A street	9100	0	274702	5016855	37.98 (c)	0	0	20900	2009.31	Right	0.017	0.000	0	0.000	0.100	0	0	0
A city	99999	9999 -99- 9999	0	99 A street	1000	2	274770	5016843	37.95 (c)	0	59100	15000	2012.55	Right	0.045	0.000	0	0.000	0.100	0	0	5910
A city	99999	9999 -99- 9999	0	99 A street	1000	1	274791	5016887	38.00 (c)	0	72400	10400	1960.32	Right	0.001	0.000	0	0.000	0.100	0	0	7240
A city	99999	9999 -99- 9999	0	99 A street	1000	1	274697	5017055	37.95 (c)	0	95800	19500	1787.51	Right	0.051	0.000	0	0.000	0.100	0	0	9580
A city	99999	9999 -99- 9999	0	99 A street	1000	1	274658	5017191	37.22 (c)	0	69600	19800	1642.46	Right	0.780	0.000	0	0.000	0.100	0	0	6960

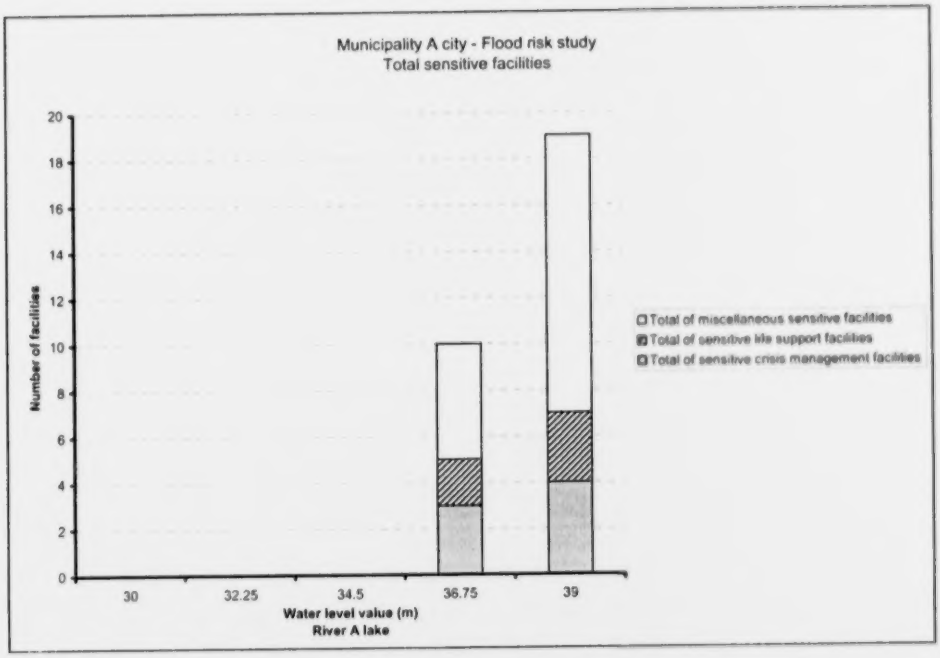
Appendix B – Examples of Impact Curves from CONSEQ

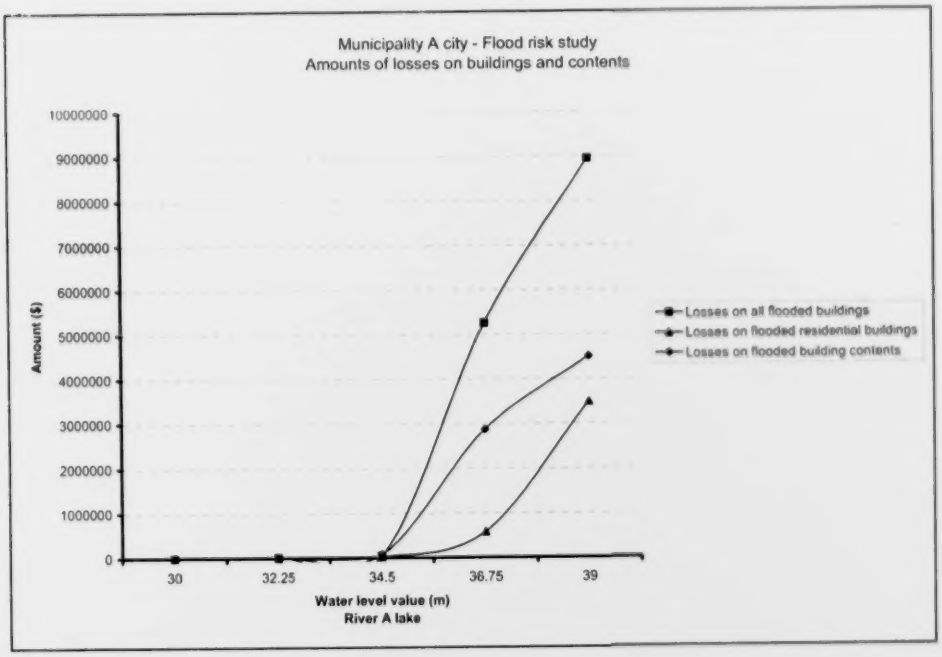


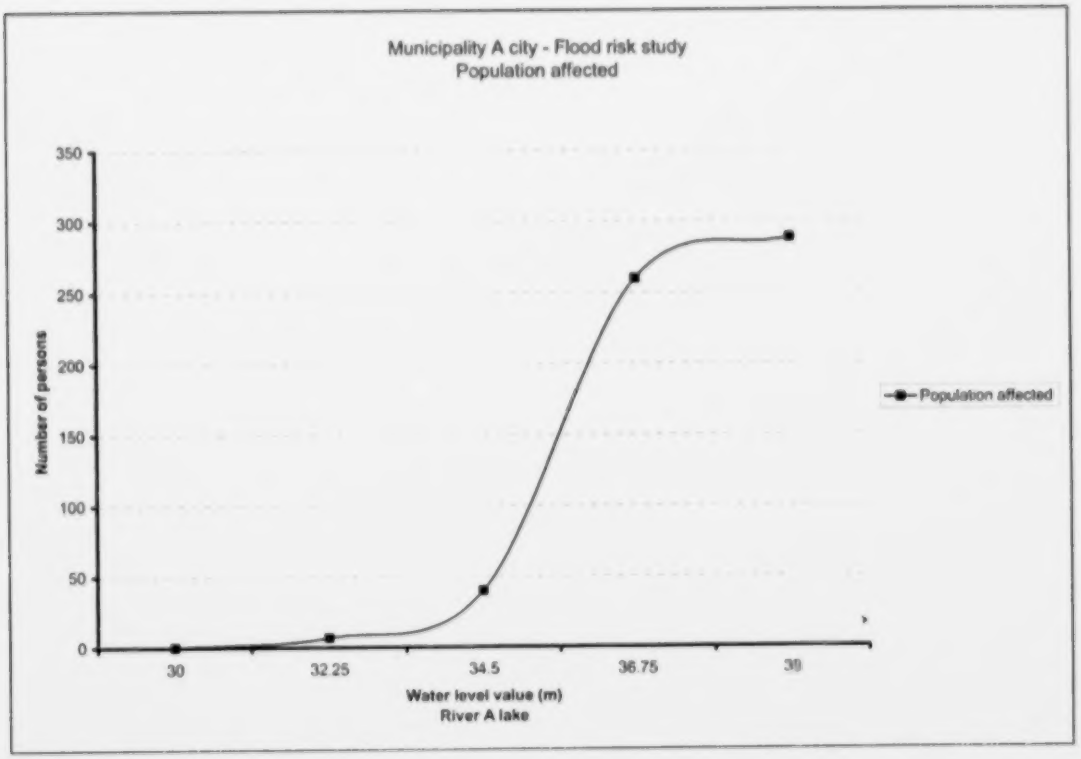



Municipality A city - Flood risk study
Sensitive life support facilities
Number of facilities
0
1
2
3
4
5
6
7
30
32.25
34.5
36.75
39
Water level value (m)
River A lake
Health services
Filtration plant (water)


Municipality A city - Flood risk study
Miscellaneous sensitive facilities
Number of facilities
0
1
2
3
4
5
6
30
32.25
34.5
36.75
39
Water level value (m)
River A lake
Schools
Day care centres
Churches
Nursing homes


Municipality A city - Flood risk study
Total sensitive facilities
Number of facilities
20
18
16
14
12
10
8
6
4
2
0
30
32.25
34.5
36.75
39
Water level value (m)
River A lake
Total of miscellaneous sensitive facilities
Total of sensitive life support facilities
Total of sensitive crisis management facilities


Municipality A city - Flood risk study
Amounts of losses on buildings and contents
Amount ($)
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
30
32.25
34.5
36.75
39
Water level value (m)
River A lake
Losses on all flooded buildings
Losses on flooded residential buildings
Losses on flooded building contents


Municipality A city - Flood risk study
Population affected
350
300
250
200
150
100
50
0
Number of persons
30
32.25
34.5
36.75
39
Water level value (m)
River A lake
Population affected

Appendix C – Examples of Impact Curves with Exposure Levels

Figure 1: Example showing exposure levels of a population of flood

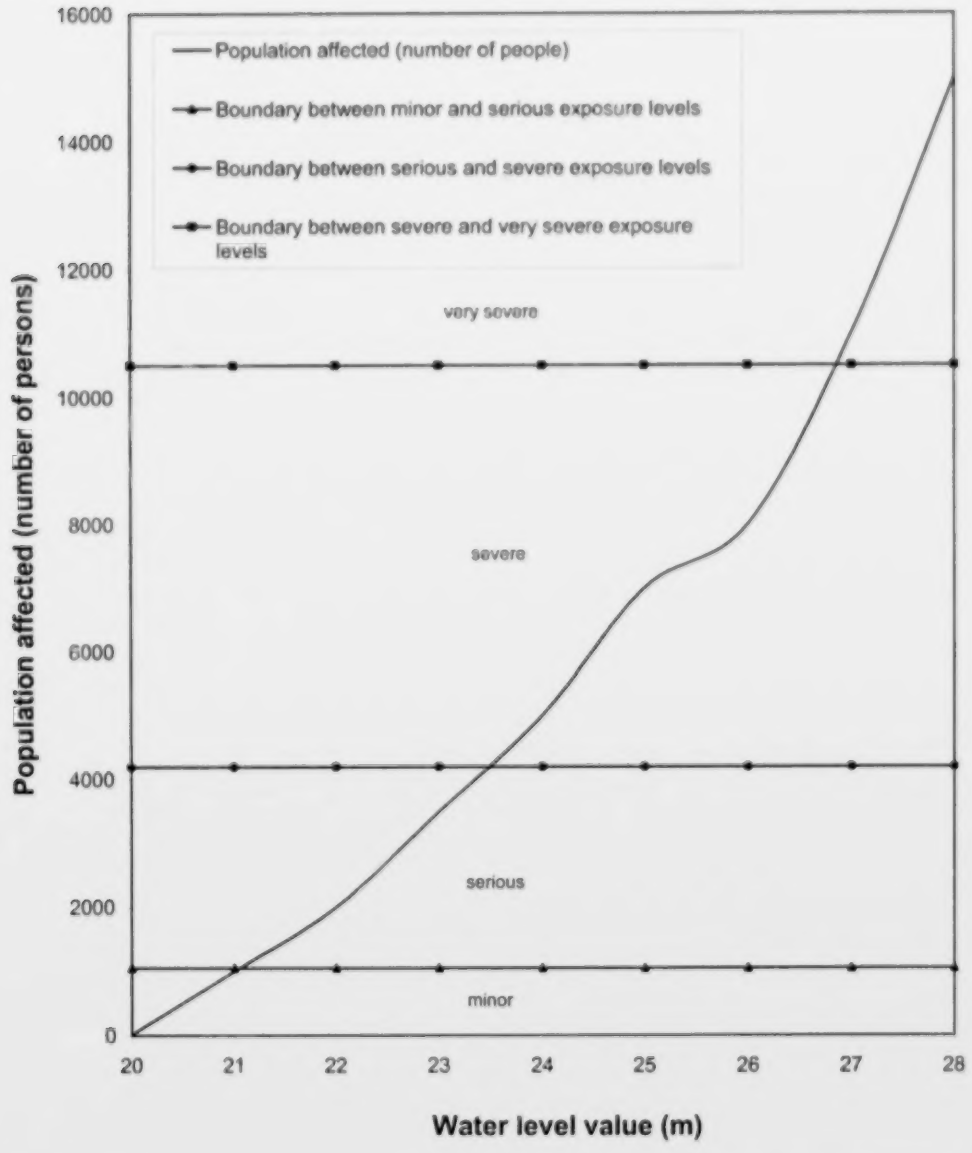
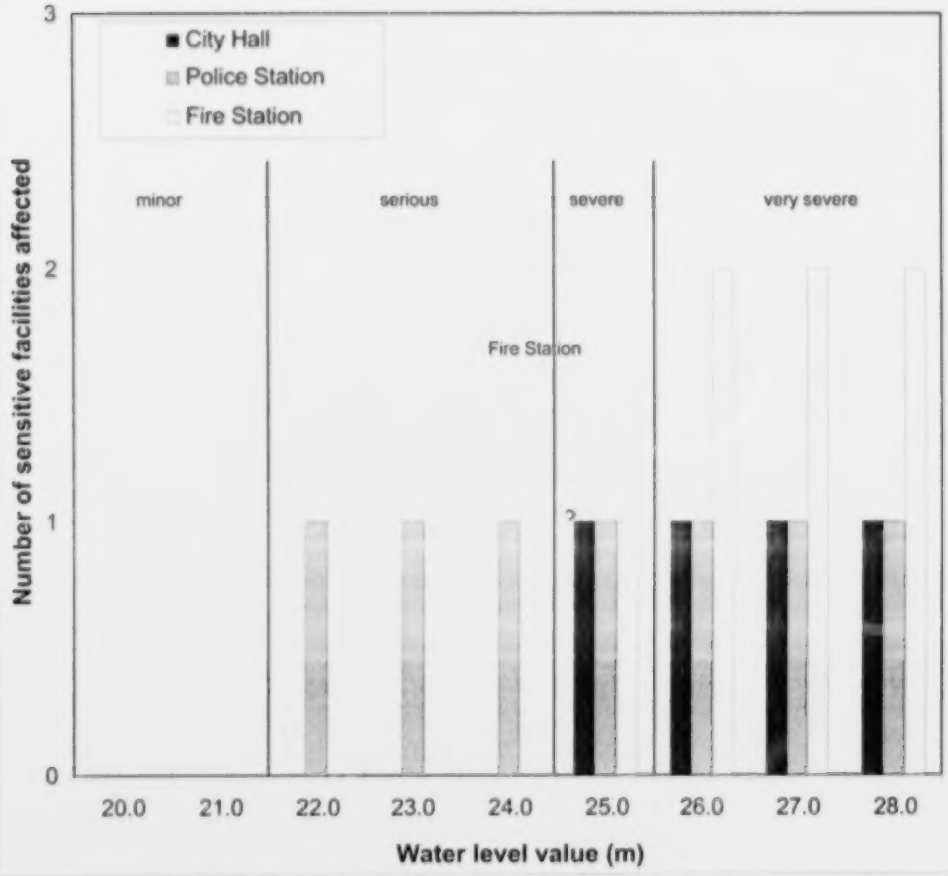


Figure 2: Example showing exposure levels for sensitive crisis management facilities



Appendix D – Description of Property Assessment Codes (Quebec City, 1999)

Entities	Code
Entities related to various types of buildings	
Office buildings	6000
Residential buildings	1000
Churches, synagogues, temples and other religious activities	6911
Crisis management entities	
Fire stations	6722
City halls	6710
Police stations	6721
Entities related to health institutions	
Hospitals	6513
Local Community Services Centres (LCSCs)	6532
Homes for the needy	6542
Nursing homes	6531
Other social centres and services	6539
Entities related to educational institutions	
Kindergartens, primary and secondary schools	6811-6814
Universities, comprehensive high schools, technical schools	6821-6823
Nurseries, night child care centres	6543
Day care centres	6541
Entities related to the army	
Civil defence	6723, 6751-6759
Communication entities	
Communications, telephone centres and systems	4711-4719
Communications, telegraph centres and systems	4721-4729
Communications, radio stations	4731-4739
Communications, television centres and systems	4741-4749
Radio and television broadcasting centres and systems	4751-4759
Other communications centres and systems	4790

Entities	Code
Transportation entities	
Railroads and subways	4111-4119
Motor vehicle transportation (infrastructure)	4211-4219, 4221-4229, 4291-4299
Air transportation (infrastructure)	4311-4319, 4391-4399
Marine transportation (infrastructure)	4411-4419, 4490
Public roads	4510-4990
Entities related to life support systems	
Filtration plants	4832
Electrical infrastructure	4811-4819
Sewage treatment plants	4841
Gas (infrastructure)	4861-4869
Oil infrastructure	4821-4829
Entities related to industries with potential environment impacts	
Rubber and plastic products industry	2213-2299
Paper and paper products industry	2911-2999
Recovery and sorting of polluting and toxic materials	4875
Oil and coal products industry	3711-3712, 3790
Chemical industry	3821-3899
Chemical drugs and related products wholesalers	5121
Agricultural chemicals wholesalers	5157
Entities related to industry and business	
Food and beverage industry	2011-2019, 5141-5149, 5411-5499, 5001-5020
Printing, publishing and related industries	3011-3050
Metal processing industry	3111-3190
Metallic products industry	3210-3299
Machinery industry	3310-3399
Asbestos products industry	3692
Butchering and meat processing industry	2011-2019
Paint retailers	5230
Service stations	5531-5533
Dumps and garbage disposal entities	4851-4859
Leather and related products industry	2310-2390
Textile industry	2410-2499
Clothing industry	2612-2699

Entities	Code
Clothing and cloth wholesalers	5131-5134
Other wholesaling businesses	5161-5169, 5171-5173, 5181-5189
Animal wholesalers	5155-5156
Other retailers	5212-5270, 5310-5399, 5511-5599 5610-5699, 5711-5740
Miscellaneous electric and electronic products industry	3510-3599
Miscellaneous entities	
Sports entities	7221-7229
Recreation parks	7610
Recreational and ornamental parks	7620
Amusement parks (outdoors)	7312
Golf courses	7411-7412
Undeveloped and unused land	9100
Unused forest	9220
Nature reserves	9211-9219
Other unused land and water areas	9900

Appendix E – Flood Data Sheets

Flood Data Sheet
City Hall
- Validation (City Hall in fact located in the flood zone). - Levels of functionality of City Hall crisis management based on increases in water levels: ✓ telecommunications functionality ✓ municipality services functionality ✓ emergency services functionality ✓ others - Levels of functionalities of the administrative aspect of City Hall based on increases in water levels: ✓ municipal documents functionality ✓ equipment functionality ✓ others - Evacuation mechanisms: ✓ evacuation method ✓ evacuation time - Alert mechanisms - Return-to-normal management: ✓ clean-up measures ✓ clean-up time ✓ business recovery activities

Flood Data Sheet

Fire Station

- Validation (fire station in fact located in the flood zone)
- Levels of functionality of the fire station based on increases in water levels:
  - ✓ total functionality
  - ✓ telecommunications functionality
  - ✓ functionality based on the dangerousness of products
  - ✓ vehicles functionality
  - ✓ personnel functionality
  - ✓ others
- Evacuation mechanisms:
  - ✓ evacuation method
  - ✓ evacuation time
- Alert mechanisms
- Return-to-normal management:
  - ✓ clean-up measures
  - ✓ clean-up time
  - ✓ business recovery activities

Flood Data Sheet

Police Station

- Validation (police station in fact located in the flood zone)
- Level of functionality of the police station based on increases in water levels:
  - ✓ total functionality
  - ✓ telecommunications functionality
  - ✓ vehicles functionality
  - ✓ functionality based on the dangerousness of products
  - ✓ personnel functionality
  - ✓ prisoner management functionality
  - ✓ others
- Evacuation mechanisms:
  - ✓ evacuation method
  - ✓ evacuation time
- Alert mechanisms
- Return-to-normal management:
  - ✓ clean-up measures
  - ✓ clean-up time
  - ✓ business recovery activities

Flood Data Sheet

School or Day-Care Centre

- Validation (school or day-care centre in fact located in the flood zone).
- Evacuation mechanisms:
  - ✓ evacuation method
  - ✓ evacuation time
  - ✓ management of children
  - ✓ parent information
- Alert mechanisms
- Return-to-normal management:
  - ✓ clean-up measures
  - ✓ clean-up time
  - ✓ business recovery activities

Flood Data Sheet

Hospital or Other Health Institution

- Validation (hospital or other institution in fact located in the flood zone)
- Level of functionality of hospitals and other institutions based on increases in water levels:
  - ✓ total functionality
  - ✓ telecommunications functionality
  - ✓ patient functionality
  - ✓ functionality based on the dangerousness of products
  - ✓ personnel functionality
  - ✓ equipment functionality
  - ✓ others
- Evacuation mechanisms:
  - ✓ evacuation method
  - ✓ evacuation time
  - ✓ patient management
  - ✓ patient relocation
  - ✓ family information
- Alert mechanisms
- Return-to-normal management:
  - ✓ clean-up measures
  - ✓ clean-up time
  - ✓ business recovery activities

Flood Data Sheet
Business at Environmental Risk
- Validation (business in fact located in the flood zone) - Evaluation of real environmental risk - Notification of risk to the company - Validation of the existence of an in-house emergency plan - Coordination of in-house emergency plan with municipal emergency measures

Flood Data Sheet
Filtration Plant (Water)
- Validation (plant in fact located in the flood zone) - Levels of plant functionality based on increases in water levels: ✓ total functionality ✓ telecommunications functionality ✓ equipment functionality ✓ functionality based on the dangerousness of products ✓ system functionality ✓ personnel functionality ✓ others - Evacuation mechanisms: ✓ evacuation methods ✓ evacuation times - Alert mechanisms - Measures for remedying the lack of potable water: ✓ number of people affected by the lack of water ✓ daily quantity (volume) of water ✓ distribution method ✓ measures for obtaining water - Fire risk management - Return-to-normal management: ✓ clean-up measures ✓ clean-up time ✓ business recovery activities

Appendix F – Examples of Failure Curves

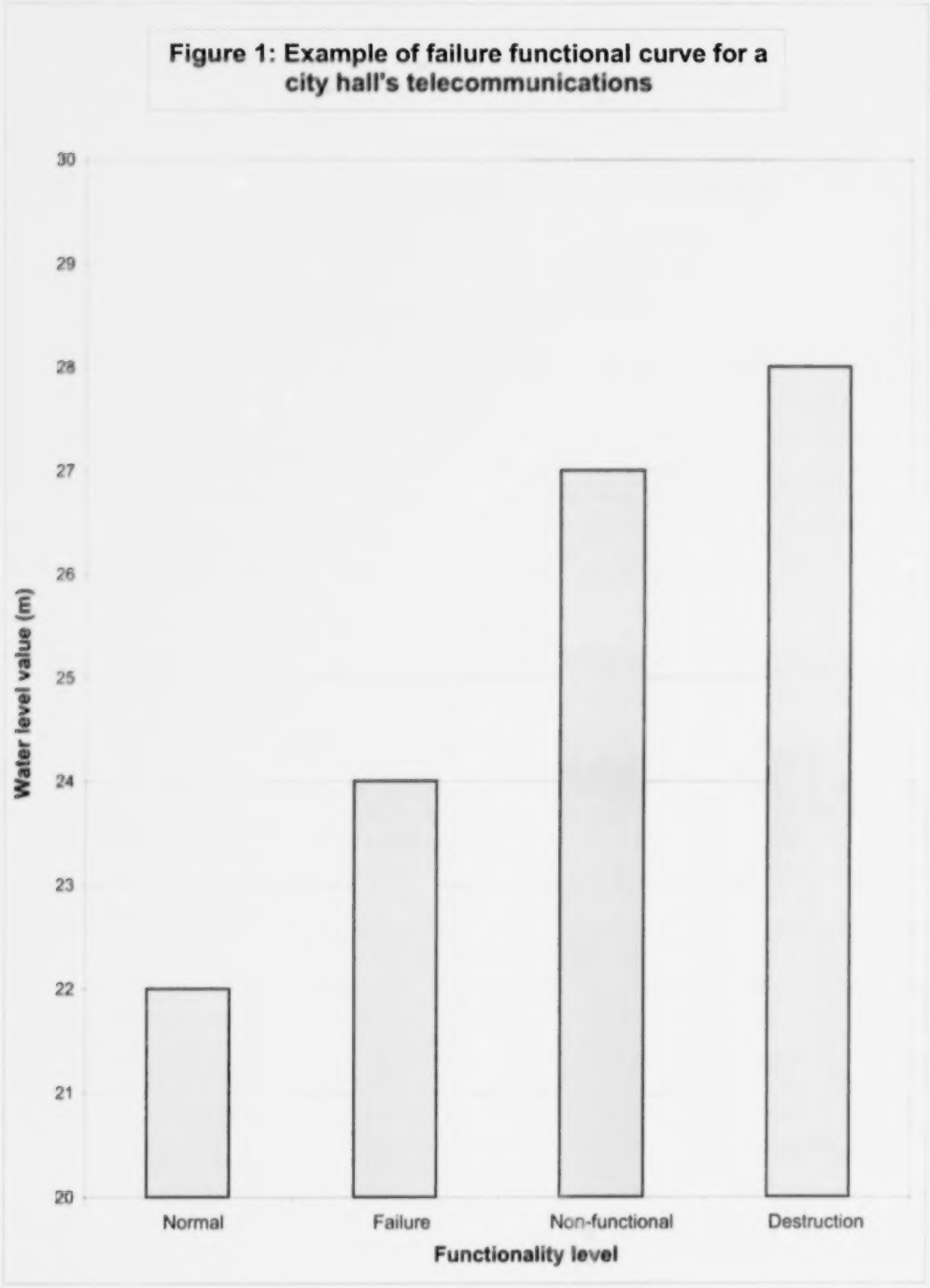


Figure 2: Example of a failure causality curve for a city hall